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MULTIWAVELENGTH LASER PROPAGATION STUDY -- II

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SUMMARY

A series of significant multiwavelength laser propagation experiments have been conducted with point-source transmitters and independent determinations of turbulence strengths. Under non-saturated scintillation conditions, we find that the theoretical wavelength prediction of log amplitude variance is valid. Also, we find that the near- and far-infrared wavelengths do <u>not</u> saturate at lower variances than visible wavelengths, and large infrared variances have been measured. We find that different techniques for measuring the strength of turbulence yield different (but related) results.

We have found that the multiwavelength covariance characteristics are usually independent of conditions and are near theoretical values, although certain anomalous results suggest limitations in the extent of the inertial subrange turbulence model. We have found that large receiver apertures do not result in the degree of reduction in total signal fluctuations that would be expected from the theory. Finally, we have found that simultaneous records of changing variances and turbulence strengths yield interesting characteristics which may be related to the stationarity of the medium.

CONTENTS

I. INTRODUCTION AND SUMMARY

During the period since the preceding Quarterly Progress Report, we have conducted a series of significant experiments in multiwavelength laser propagation with a virtual point-source (spherical wave) transmitter configuration. As discussed in the preceding report, the customary use of a finite, divergent transmitter beam does not result in data which may be simply compared to the predictions of spherical wave theory. Also, an important feature of the present data is that they are backed up by several independent determinations of the strength of the turbulence. Hence, although much more data must be gathered before firm, general conclusions can be drawn, the results of our present experiments suggest new and important hypotheses.

In particular, during unsaturated conditions we find that the theoretical $k^{7/6}$ dependence of log amplitude variance is reasonably well verified within experimental spread. Also, we find that the near- and far-infrared wavelengths do <u>not</u> saturate at lower variances than visible wavelengths, and we have seen variances as high as 0.63 and 0.15 at 1.15 and 10.6 micron wavelengths, respectively. We find that different techniques for measuring the strength of turbulence yield different (but related) results.

We have found that the multiwavelength covariance or lateral correlations of log amplitude are usually independent of conditions and are near theoretical values, although certain anomalous results have been noted as discussed later. These anomalies may relate to a relatively large inner scale (limited inertial subrange). Also, we have confirmed other reports that large receiver apertures do not result in the expected degree of reduction in total signal variance, and we have therefore shown that this suprising phenomenon is not fundamentally due to the use of a finite transmitter aperture.

Finally, we find that simultaneous records of variance and turbulence strengths vs. time yield interesting characteristics, which may be related to considerations of stationarity of the medium.

In the following sections, we discuss the above aspects in detail.

II. EXPERIMENTAL RESULTS

A. GENERAL MEASUREMENTS PROGRAM

A Standard Operating Procedure was established in which we measured the following quantities during experimental "run":[1]

1. Strength of turbulence (C_n^2) through determination of the mean-square temperature differential between two thermal microprobes ($<\Delta T^2>$)

2. C_n^2 from the slope of the probability curve for ΔT on gaussian probability axes

3. C_n^2 ("optical") inferred from the variance (probability slope) of the log amplitude scintillations of a 6328Å portable laser located at 500 feet from the receiver

4. Simultaneous log amplitude probability distributions and variances $[C_\ell(0)]$ over a one mile path, for 4880Å, 1.15 microns, and 10.6 microns

5. Simultaneous log amplitude covariances $[C_\ell(r)]$ for the same three wavelengths

6. Simultaneous spectra of amplitude scintillations for the same three wavelengths*

Items #1-3 above are performed simultaneously, followed by #'s 4 and 5 in quick sequence, followed typically by a repeat of 1-3. The entire data run takes less than 30 minutes. Wind speed and direction (at both ends of the path), temperature, and barometric pressure are recorded continuously.

The inverse Fresnel number for the 4880Å transmitter is on the order of 10^4 and for 10.6 microns is 10^2. At 1.15 microns, the transmitter is larger but contains several transverse modes and hence may be expected to yield results which are in good agreement with those from a point source; this was borne out by the experiments. The receiver aperture at all wavelengths is 3mm.

Preliminary experiments were also performed for ancillary quantities, as follows:

1. Log amplitude probability distribution and variance at 4880Å vs. receiver aperture up to 12½ inches diameter.

2. High-frequency cut-off of the spectrum of temperature fluctuations, as an indication of the size of the inner scale

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*This determination is not presently feasible for very light transverse wind conditions, since our spectrum analyzer is inaccurate at or below 10 Hz. However, we are obtaining an analyzer of greater low-frequency resolution.

3. Simultaneous recordings of the log amplitude variances and C_n^2 vs. time.

As appropriate, these measurements will be incorporated in the Standard Run described above. Also, at a later date, transmitter apertures will be systematically increased. However, at the present time we are concentrating on obtaining a sufficient quantity of data to support preliminary conclusions.

B. NATURE OF RESULTS

A typical oscillogram of three-wavelength amplitudes is shown in Figure 1. Unlike earlier results for finite apertures, the point-transmitter scintillations shown here are only weakly correlated between wavelengths. Except for highly non-stationary conditions, the log amplitudes were always log normal(for both saturated and nonsaturated conditions) within the accurate probability resolution range of our technique (Fig. 2). We can expand the probability tails at a later date, should this prove desirable.[2]

Covariance results were relatively consistent and independent of conditions, including the saturation of scintillations. We define the transverse log amplitude correlation length r_a as that (horizontal) separation of detectors which results in the following condition:

$$C_\ell(r_a) = \frac{1}{e} C_\ell(0) \qquad (1)$$

The experimental value of r_a was generally somewhat smaller than that of the theory of Ref. 3, especially at 10.6 microns. A typical covariance result is shown in Figure 3. Major anomalies in covariance were occasionally noted, and will be discussed below.

The spectra of scintillations are exemplified by the smoothed curves of Figure 4. Although the curves are not readily normalized instrumentally, due to the extrapolation necessary to obtain the O-Hz level, the "bandwidth" corresponding to (1/e) of this level is readily obtained and in all cases agreed rather well with the transverse wind component and measured value of r_a. This substantiates the "frozen-in" structure of the scintillation pattern.

The three methods of obtaining C_n^2 proved highly interesting. The approach was suggested by the work of Ref. 4. We confirm the preliminary findings of that report, in which it was stated that the temperature fluctuations (ΔT) depart seriously from a gaussian distribution.* Representative results for three different runs are shown in Figure 5, showing (1) a good gaussian characteristic; (2) a pronounced "tail" all but obliterating a gaussian characteristic; and (3) a curve best represented as two discrete gaussians due to a sudden change in turbulence conditions (e.g., when the sun emerges from behind a cloud). In all cases, the optical/IR scintillations were log normal.

The typical characteristic evidenced a linear (i.e. gaussian) region, with definite tails, and consequently the value of C_n^2 obtained directly from $(\Delta T)^2$ was always larger than that from the probability slope. In addition, the C_n^2 inferred from the short-path optical scintillations always fell in between the other two values. The amount of spread in the three values depended on the degree of nongaussian behavior, and the one-mile scintillations (e.g. at 10.6 microns, which was never saturated) were fairly well related to the latter two determinations of C_n^2. Clearly, the interaction of the optical filter

*However, we did not see clear "spiking" in the temporal ΔT behavior.

function and the turbulence spectrum should be thoroughly investigated.[5-8] This will be discussed more fully below.

C. REVIEW OF RESULTS

Table I contains a review of results from selected runs which illustrate various aspects of the phenomena.

It should be pointed out initially that the accuracy inherent in the instrumentation and approach is very good, since very large dynamic ranges, and probability slope methods, are used. However, it is characteristic of atmospheric phenomena that stationarity of the medium is a useful approximation at best, and hence, the spread in results will always be substantial. This will be directly illustrated in a later section.

In Table I, the theoretical values of $C_\ell(0)$ are obtained from the standard, Rytov-based theory for a point source (Ref. 3). Hence, these values should not be expected to predict saturation, i.e., the limitation of experimental $C_\ell(0)$ to values on the order of 0.6.

Finally, we point out that although our range is nominally flat and uniform, it is not as ideal in this regard as e.g. the Emerson Dry Lake site (Ref. 4). In the case of a Westerly wind (Runs #5 and 6), there are upwind trees over the portion of the path near the receiver. These characteristics, which are logistically necessary, do not comprise a serious limitation to the goals of this program, since the distribution of any nonuniformity in C_n over the path weights each wavelength identically. Hence, although this may contribute some to the spread in the relationship between independently measured C_n^2 values (at the receiver) and nonsaturated scintillation variances, the validity of the theoretical $k^{7/6}$ dependence of variance, and the wavelength dependencies of saturation, are investigated without difficulty.

We now point out the salient implications of each run.

Run #1 may be characterized as "typical" of afternoon data on a clear winter day with some wind. Scintillations at 4880Å are essentially saturated, and at other wavelengths C_n^2 from $(\Delta T)^2$ predicts variances of 2-3 times more than the observed values, due to the nongaussian behavior of ΔT. The measured values of r_a agree with theory for 4880Å and are somewhat low at 10.6 μ. The scintillation bandwidth is reasonably consistent with r_a and the transverse wind velocity.

In Run #2, there was very little wind and hence there may have been insufficient energy for broad applicability of the inertial subrange.[4] The most noticeable anomaly is the unusually high value of variance at 4880Å, a result which was obtained with repeated trials. The variances at the infrared wavelengths are accurately predicted from C_n^2(C) or the "optical C_n^2." This value agrees within 50% of that determined from the ΔT probability slope, while that from $(\Delta T)^2$ is 3.6 times higher. Values of r_a are typical. A further evidence of a large inner scale for this run will be discussed later.

In Run #3, a higher wind was sustained, and scintillations were not saturated. The ratio of variances is in very good agreement with the $k^{7/6}$ prediction. However, there are considerable tails on the temperature probability distribution, and a large value for C_n^2 (A). The variances agree most closely with the predictions from C_n^2(C). Values of r_a are typical, and scintillation bandwidths and transverse wind are consistent with these values.

Run #4 is typical of data being obtained as the spring weather becomes warmer, and 4880Å scintillations are saturated. Very severe tails on the ΔT distribution were evidenced, and there was a large spread between the three measurements of C_n^2, with the optical value fairly well predicting the observed variances. The low wind and high value of r_a at 4880Å may indicate a large inner scale.

In run #5, taken in the evening, the wind was slight but the tail in ΔT and spread in $C_n{}^2$ measurements were relatively small. 4880Å was saturated, and the other variances were best predicted by the optical $C_n{}^2$, or even that from $(\Delta T)^2$.

Finally, run #6 was taken during the early morning under relatively light turbulence conditions. The turbulence was considerably non-stationary, and values of r_a were quite anomalous, indicating a breakdown in the subrange.[9] The variances (a) were taken from probability curves, which were somewhat erratic due to nonstationarity; the values (b) were taken directly from dynamic recordings of $C_\ell(0)$ vs. t at coincident relative maxima, as discussed later. The latter values are most closely related to $C_n{}^2(C)$.

The results of Runs 2, 4, and 5 indicate that saturation does not occur at lower variances for longer wavelengths. This is further supported by a measured variance at 10.6μ of 0.15, as discussed below. This conclusion contradicts highly conjectural statements* made previously,[4,10] and would resolve a serious dimensional difficulty.[10,11] The result, if continually supported by further experiments, has important implications for systems operating at 10.6 microns, since the dynamic range of fading is given approximately by

$$D.R. \approx 100\, C_\ell(0)\ \text{dB} \qquad (2)$$

*In Ref. 10, these statements were based on sparse experimental data with no $C_n{}^2$ backup. In Ref. 4, the data on IR scintillations were again sparse, and the variances predicted from $C_n{}^2$ were not large enough to test the presence of IR saturation.

For instance, under the conditions of runs #2 and 4, and the high 10.6 micron variance reported below, saturation at the $[C_\ell(0) \approx 0.6]$ level is distinctly possible for 10.6 micron propagation over a low, 10 mile path.

D. SIZE OF THE INNER SCALE

It has been recognized by theoretical[7,12] and experimental[4,9] investigators that the extent of the inertial subrange should be known for each experimental condition. That is, although the Kolmogorov turbulence spectrum leads to results of obvious utility (and there exists no useful alternative model), various effects under certain diurnal and wind conditions suggest limitations on the subrange, which in turn lead to anomalies in measured variances, co-variances, etc. In particular, it would be highly desirable to know the non-zero value of the inner scale, e.g. for use with the optical filter function.[7,8] It may be pointed out that the theoretical covariance result[3] is valid only when the receiver is in the far field of the inner scale.

Although the scintillation phenomena may be used to "probe" the subrange[7], for example using a variable transmitter aperture, a more direct approach for our purposes would be to determine the inner scale from the spectrum of temperature fluctuations.[12] We are currently working on this problem experimentally, using our thermal microprobe, and if successful, we will inforporate this determination into the Standard Operating Procedure.*

An indication that the method may be successful may be seen from Figure 6. Although the theoretical rms spectrum falls off as $(\text{frequency})^{-5/6}$, a distinct flattening-out is observed well above the instrumental noise. This characteristic, which is for Run #2 above, implies

*An attempt to directly measure the breakdown of the "2/3 law" dependence of the mean square differential temperature between two points is hampered by the impracticality of bringing probes suitably close together, especially without disturbing the temperature field.

an inner scale of approximately 2 cm when the average wind velocity is taken into account.

We will improve the method by (1) utilizing a spectrum analyzer of greater capability at very low frequencies; and (2) utilizing discrete spectral points over a logarithmic amplitude and frequency scale. It is necessary that the full dynamic range of the spectrum analyzer be utilized, so that ΔT must be taken directly from the microprobe (Fig. 7) rather than from an FM magnetic tape recording.

E. APERTURE AVERAGING

It has been reported by Fried and co-workers[13,4] that unexpectedly large fluctuations remain when the scintillating beam is received by a large aperture. It was speculated that the effect relates to finite transmitter aperture sizes.

We have conducted preliminary receiver aperture averaging experiments in order to determine the presence and extent of this effect for our point-source transmitter at 4880Å. (The work will be extended to other wavelengths at a later date.) We find that the aperture-averaged reduction in total signal variance is somewhat better than that reported in Ref. 4, but nevertheless that a substantial fluctuation remains. Furthermore, the effect is observed when simultaneous measurements of covariance indicate a zero correlation for $r > r_a$, so that e.g. beam wander cannot explain the phenomenon. Thus the effect remains a mystery.

The aperture-averaging results are shown for two runs in Figure 8. The results were independent of the detector configuration (focused photodiode vs. unfocused PMT). The data for typical covariance conditions and a saturated variance show a residual, for the total aperture averaged variance on the order of 10% of $C_\ell(0)$. The log amplitude probability distribution is gaussian (Fig. 9). The other (nonsaturated) data are for the anomalously large covariance conditions of Run #6, and, although larger intermediate apertures are necessary to achieve averaging, the percentage reduction at full aperture is better than that for small covariances. This is indeed surprising. Note that the nonstationarity of conditions in Run #6 is evidenced by the increase in variance at 2.5 cm over that for a point detector. However, the general results of this experiment were repeatable.

In order to compare the aperture-averaging results with a theoretical prediction, we may utilize the results of Ref. 14. Although this analysis was done for a plane wave source under Rytov (nonsaturated) conditions, the covariance characteristics for a point source and/or for saturated conditions are not materially different. To summarize the results of this analysis, we define a transverse scintillation correlation length $r_a' = (4L/k)^{1/2} = 2.24$ cm for our path at 4880Å. Then, although Ref. 14 deals directly with $C_I(0)$ rather than $C_\ell(0)$, it may be deduced from the results presented there that

$$C_{\ell\,\substack{\text{large}\\ \text{aperture}\\ \text{diameter } D}} \approx (D/r_a')^2 \; C_\ell(0) \qquad (3)$$

This result is as intuitively expected from the independent addition of approximately $(D/r_a')^2$ independent, log normal quantities. For a 12 inch or 30 cm aperture, we would then expect a variance of 0.005 times that for a point aperture. This is an order of magnitude less than the lowest value actually measured.

F. DYNAMIC RECORDING OF C_n^2 AND VARIANCES

As discussed in the next section, the turbulent medium may be highly nonstationary. The reason may be obvious, as in the case of small clouds periodically obscuring the sun; or more subtle, as in the case of Run #6.

The three-wavelength variances vs. time for Run #6 are shown in Figure 10. The variances are well correlated, but it is obvious that their ratio is nonconstant, even though conditions were nonsaturated. This undoubtedly relates to the changing extent of the inertial subrange. For multi-wavelength comparisons under such unstable conditions, such a recording permits the use of truly simultaneous values, e.g. at a relative maximum or minimum.

A recording of thermal $[(\Delta T)^2]$ C_n^2, optical C_n^2 from a short path, and variances at 4880Å and 10.6 microns is shown in Figure 11. For this recording, the wind was blowing parallel to the path, from the receiver (where the C_n^2 instrumentation is located) to the transmitter, and the sky was partly cloudy. The two C_n^2 indications are well correlated, and the 10.6 micron curve responds to each C_n^2 peak but with a definite time delay which indicates the movement of general conditions toward the transmitter. Also, the 4880Å variance, which is saturated, is <u>anticorrelated</u> with that for 10.6 microns, which illustrates the fall-off property "beyond saturation": as C_n^2 increases further, the scintillations actually decrease. It may be noted that short-term turbulence was very large during this run, with optical C_n^2 values of $3 \times 10^{-13}\ m^{-2/3}$ and 10.6 micron variances of as high as 0.15.

G. STATISTICAL STATIONARITY CONSIDERATIONS AND THE INERTIAL SUBRANGE

There exist subtle relationships between statistical stationarity, averaging times, low temporal or spatial frequency components of the phenomena, and the interaction of the inertial subrange with the optical filter function. Although the stationarity of atmospheric phenomena can be treated with some rigor,[15] it is perhaps more fruitful to consider the direct physical implications. For example, sizeable fluctuations of the strength of turbulence (as averaged with e.g. RC= 100 seconds) may result from partly cloudy skies, gusty winds, or less discernible causes. Nonstationarity may be cyclic or monotonic in nature. To the extent that monotonic trends do not enter seriously, one may use very long averaging times to compare various interrelated experimental parameters with theoretical predictions. However, for practical questions such as the degree of fading or the short-term error rates in a communications or radar system, a failure to follow or predict shorter-term extremes of turbulence effects may result in unrealistic design appraisals.

When the medium is stationary, rapidly fluctuating phenomena such as scintillations at visible wavelengths will yield highly repeatable statistical results over e.g. 10 second averaging times, while phenomena such as 10.6 micron scintillations, with strong low frequency components, require much greater averaging times to reduce the experimental spread.* It is often somewhat difficult to define a difference between nonstationarity and large low-frequency components, except through the simultaneous monitoring of more rapidly fluctuating phenomena.

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*An experimental technique for obtaining accurate probability sweeps during changeable conditions is to magnetically record the variable (ΔT or log A) and then measure discrete probability points by repeated scans of the same time window.

A particularly important aspect of this question arises in relating the temperature fluctuations, which are dominated by low frequencies and which evidence probability characteristics which might be interpreted either as nonstationarity or as strongly nongaussian behavior, with optical/IR scintillations, which are much faster and usually log normal. It is conjectured that the nongaussian probability tails for the thermal fluctuations are generally manifestations of (slow) fluctuations with corresponding spatial frequencies which are largely outside the inertial subrange and, in most cases, outside the significant range of the optical filter function. However, since the slope of the linear probability range predicts too small a scintillation-variance, relative to the short-path optical C_n^2 determination, it must be concluded that these probability tails may not be completely neglected. A direct determination of the outer scale would be desirable, through large thermal probe separations or very-low-frequency spectral analysis of the temperature fluctuations. A related item is the optimum value of the large, series coupling capacitor in the thermal probe instrument, since we are actually measuring $\Delta T - \langle \Delta T \rangle$.

III. PLANS FOR THE FOLLOWING PERIODS

Our primary task now is to obtain sufficient quantities of point-transmitter data under a variety of conditions to substantiate our tentative conclusions. Prior to the onset of consistent good weather, we will attempt to develop the thermal determination of the inner (and possibly outer) scales to the point where these parameters may become part of a standard run. After obtaining the large body of fundamental results, we will obtain data for varying transmitter apertures.

During the late period of the follow-on program, we may find it feasible to conduct limited experiments over a much longer path. These are desirable in order to:

(1) Demonstrate 10.6 micron scintillation behavior at large variances (or saturated)

and (2) Determine whether or not a limitation occurs in the value of r_a vs. range (L), when $C_\ell(0)$ becomes saturated (at 4880Å).

The latter item is suggested by a heuristic argument. The fact that r_a increases as $(\lambda L)^{1/2}$ while the "coherence diameter" r_o decreases with range,[16] suggests that the process of setting $r_o = r_a$ will define a critical range (L_{cr}) for any given turbulence level. As pointed out in Ref. 4, the equality occurs for a particular $C_\ell(0) << 1$ which is independent of the values of L, C_n^2, and λ giving rise to this variance (This is consistent with our new experimental evidence that the saturation level is not wavelength-dependent.) We may further speculate that r_a cannot continue to grow indefinitely as L becomes much greater than L_{cr}. Such a limitation in r_a is suggested by the experimental data of Ref. 17, and has important implications regarding aperture averaging in long-path systems.

A. APPENDIX: NOISE BANDWIDTH OF THERMAL PROBE

The thermal probe system has been described in detail in recent reports on this project. Although the sensitivity of the unit is much higher than necessary for ground-based measurements, the possible use of a similar system in vertical C_n^2 profile measurements suggests that the question of ultimate sensitivity and effective noise bandwidth be discussed further.

The effective noise bandwidth, or ability of the instrument to measure small C_n^2, relates to both the response speed or i.f. bandwidth, and to the final integration time. If the two bandwidths are B_1 and B_2 respectively, the effective bandwidth is basically proportional to $(B_1B_2)^{1/2}$.

The question of SNR and limiting sensitivity becomes a rather subtle one because the "signal" is in some sense the mean change in the meter reading (over system noise)in the presence of turbulence, while the "noise" relates to the variance in this change taken over an ensemble. Without going into this question in detail here, it suffices to point out that the use of synchronous demodulation is superior, in marginal detection situations, because envelope demodulation results in the i.f. noise <u>suppressing</u> the signal and in unnecessary baseband self-convolution of the noise prior to the squaring operation.

In our unit, which uses a low-noise front-end technique but envelope demodulation for simplicity, an i.f. SNR of unity occurs for a value of C_n^2 of $2 \times 10^{-17} m^{-2/3}$. This is consistent with the residual output $(\Delta T)^2$ indication (at highest gain) corresponding to system noise. If we were to approach this level of C_n^2 e.g. at higher altitudes, we would want to use synchronous demodulation in order to prevent the suppression of marginal signals by the noise. In the present case, this is two orders of magnitude below values which we have seen.

TABLE I - SELECTED RESULTS

Run #	$C_\ell(0)$			$^{**}r_a$(cm)			$C_n^2 \times 10^{-14} (m^{-2/3})$ A From $<(\Delta T^2)>$	B From ΔT Probability	C From 500' Scintillations
	4880	1.15	10.6	4880	1.15	10.6			
1	0.51	0.20	0.016	1.35	1.55	5.3	7.2	-	-
2	0.81	0.63	0.050	1.25	1.7	4.95	36	5.3	10
3	0.28	0.096	0.0078	1.2	1.7	5.1	22	1.8	3.9
4	0.62	0.38	0.050	1.85	1.7	4.4	31	1.2	7.1
5	0.64	0.49	0.034	1.8	2.1	6.2	4.6	1.4	3.7
6	a 0.036 b 0.083	0.013 0.033	0.00075 0.0028	2.0	6.6	11	2.3	0.22	0.61

* With the exception of Run #1, the upper values are from C_n^2 (C) and the lower values from C_n^2 (B). For #1, only C_n^2 (A) was available, and is high, as discussed in the text.

**Theoretical values (Ref. 3): 1.34 cm (4880 Å); 2.07 cm (1.15μ); 6.19 cm (10.6μ).

TABLE I (continued)

*Theoretical $C_\ell(0)$			Bandwidth (Hz)				
4880	1.15	10.6	4880	1.15	10.6	Time of Day	Conditions
1.4	0.46	0.34	240	160	47	Early Afternoon	Clear, 7 mph transverse wind
1.8	0.67	0.050	-	-	-	Early Afternoon	Clear, very little wind
0.97	0.35	0.026	-	-	-		
0.72	0.26	0.020	330	203	55	Early Afternoon	Clear, 5-15 mph transverse wind
0.34	0.13	0.0093					
1.3	0.48	0.036	-	-	-	Early Afternoon	Haze, 0-2 mph transverse wind
0.22	0.082	0.0062					
0.89	0.33	0.024	-	-	-	10:00 P.M.	Clear, little wind
0.24	0.088	0.0066					
0.113	0.041	0.0031	-	-	-	7:00 A.M.	Clear, 0-2 mph transverse wind
0.041	0.014	0.0010					

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1. The terms, parameters (such as C_n^2), and instrumentation referred to in this report have been extensively discussed in the preceeding Quarterly Progress Reports, and it will therefore be assumed that the reader is familiar with the concepts.

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FIGURES

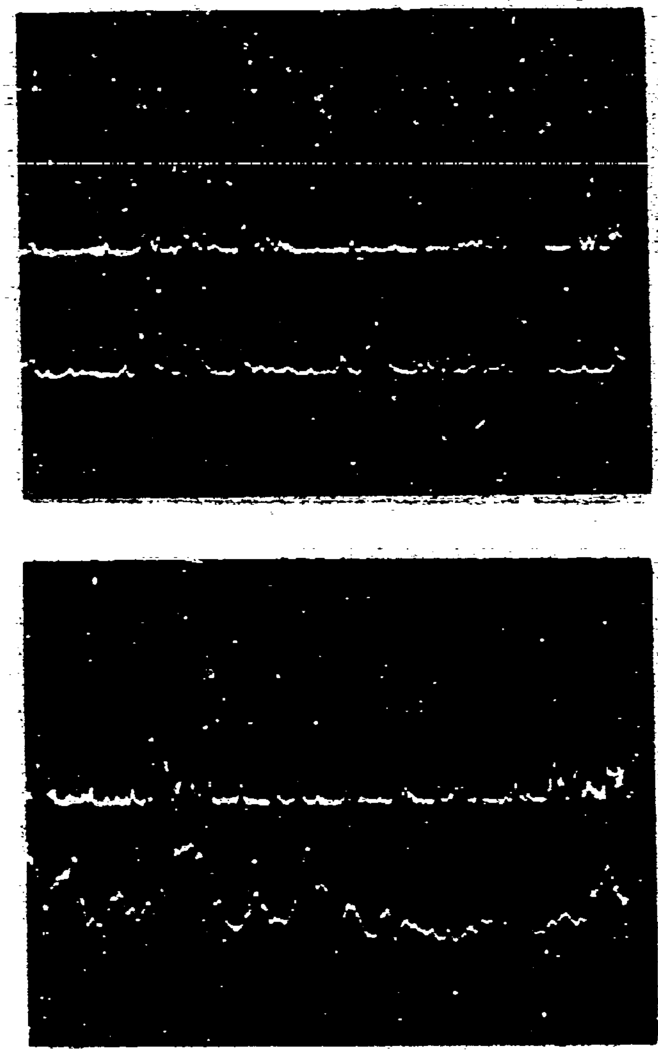


FIGURE 1

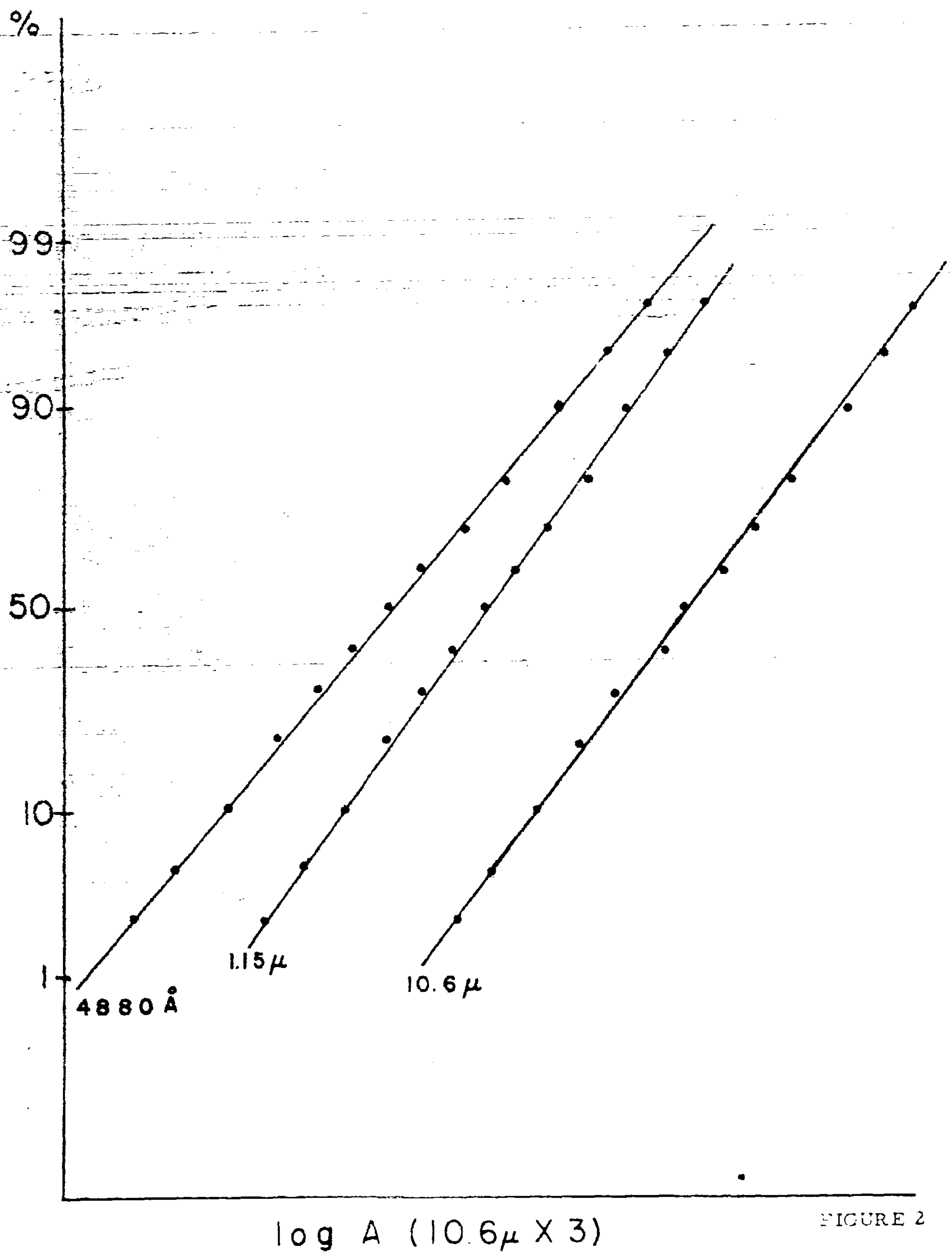


FIGURE 2

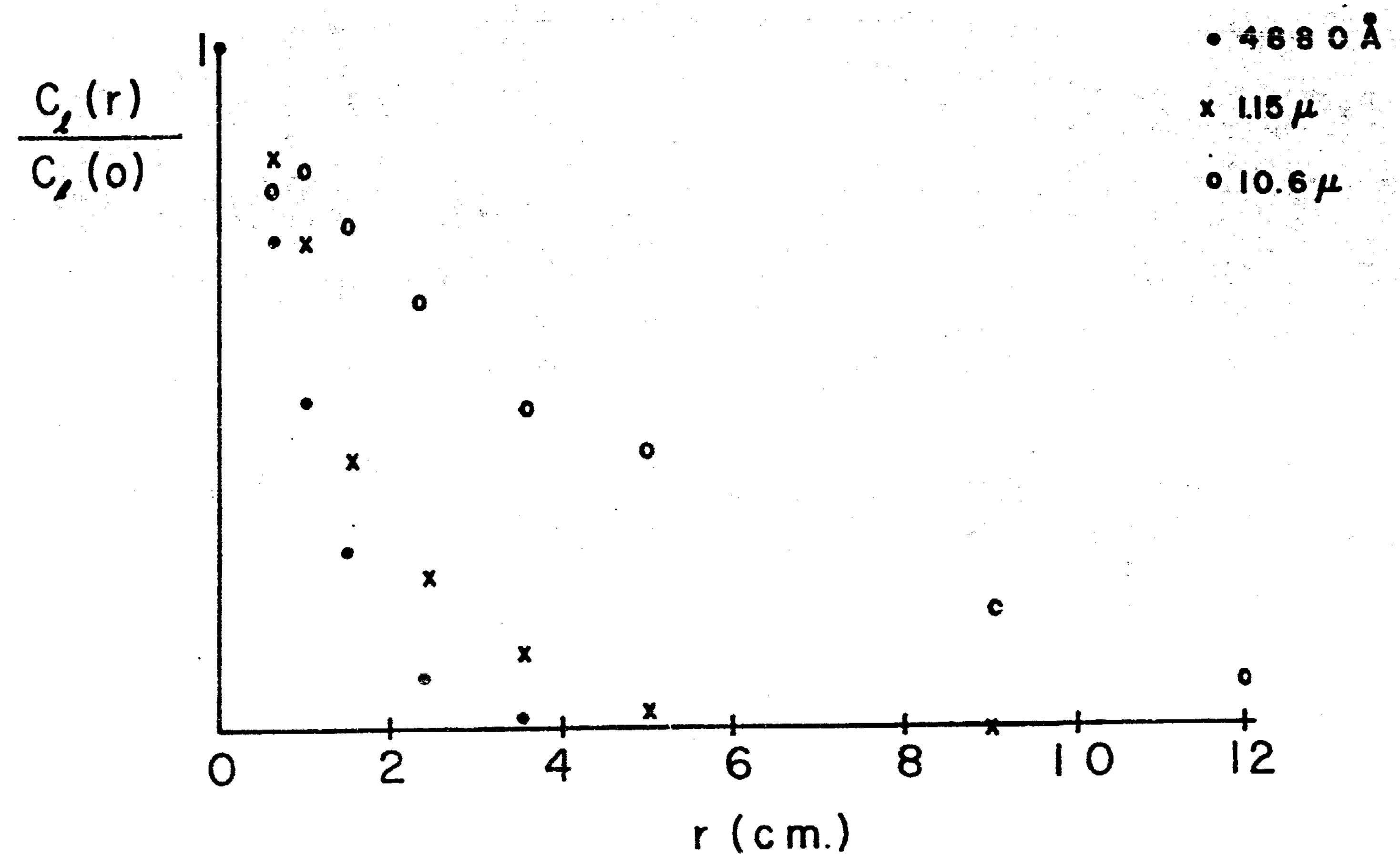


FIGURE 3

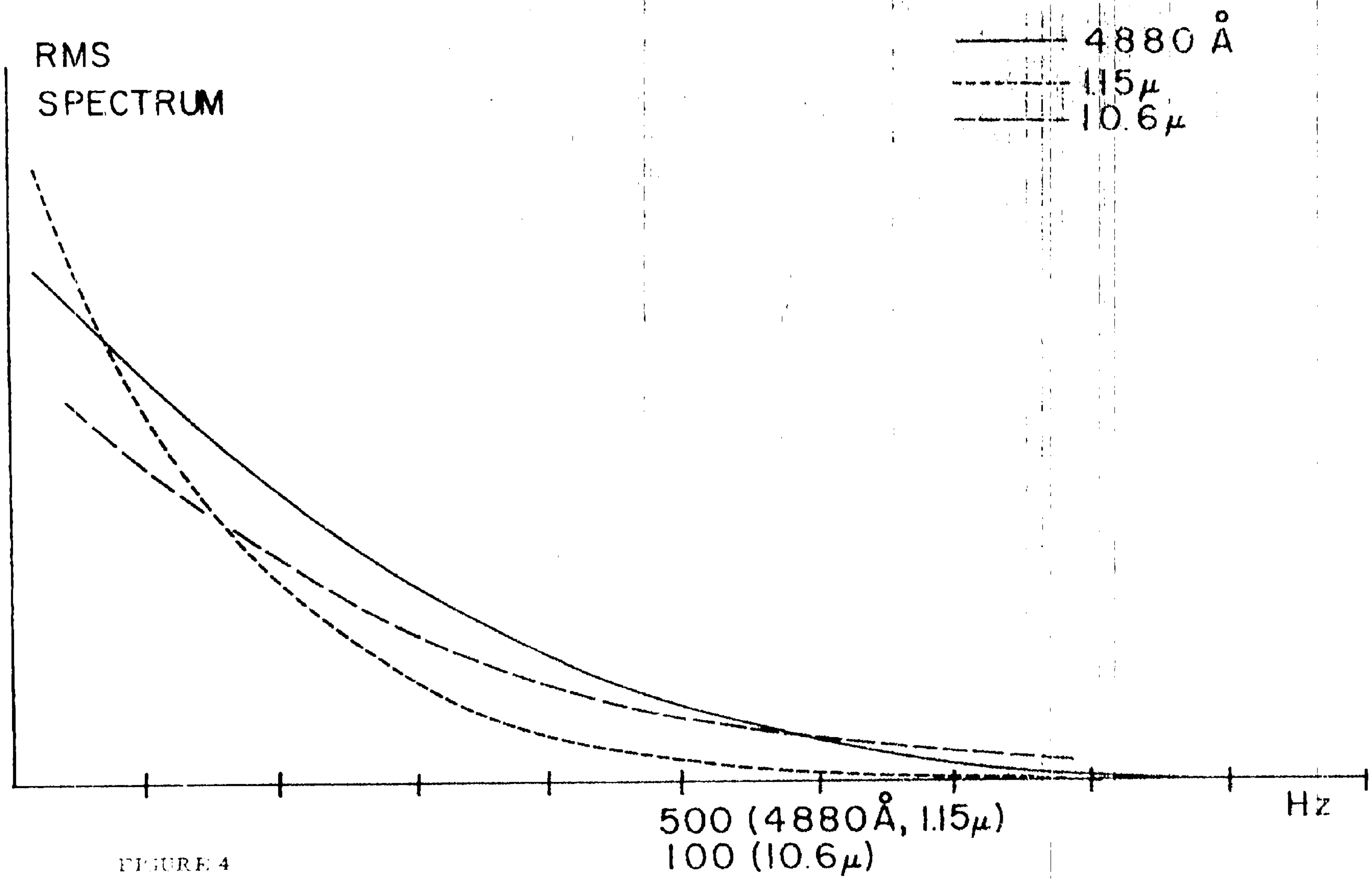


FIGURE 4

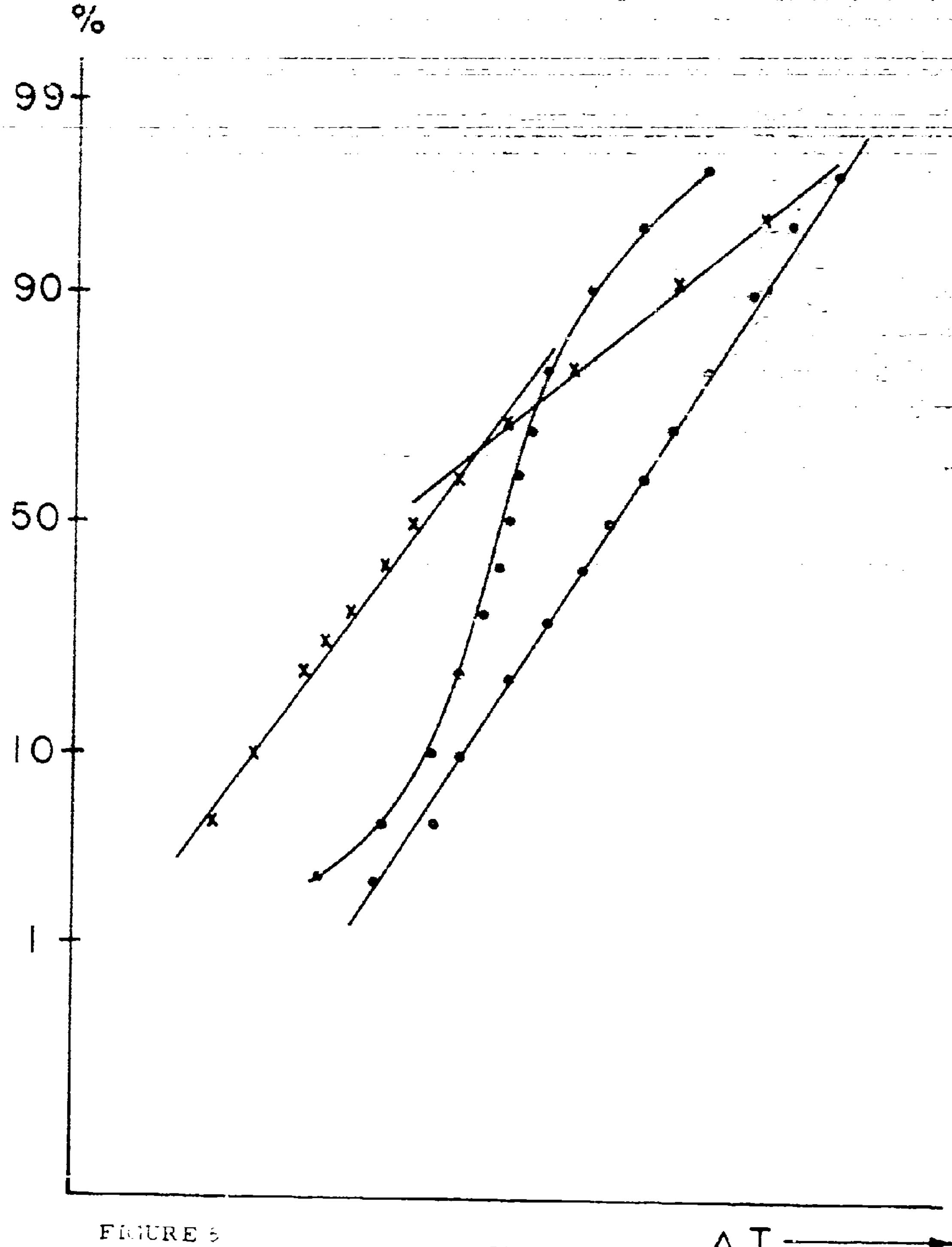


FIGURE 5

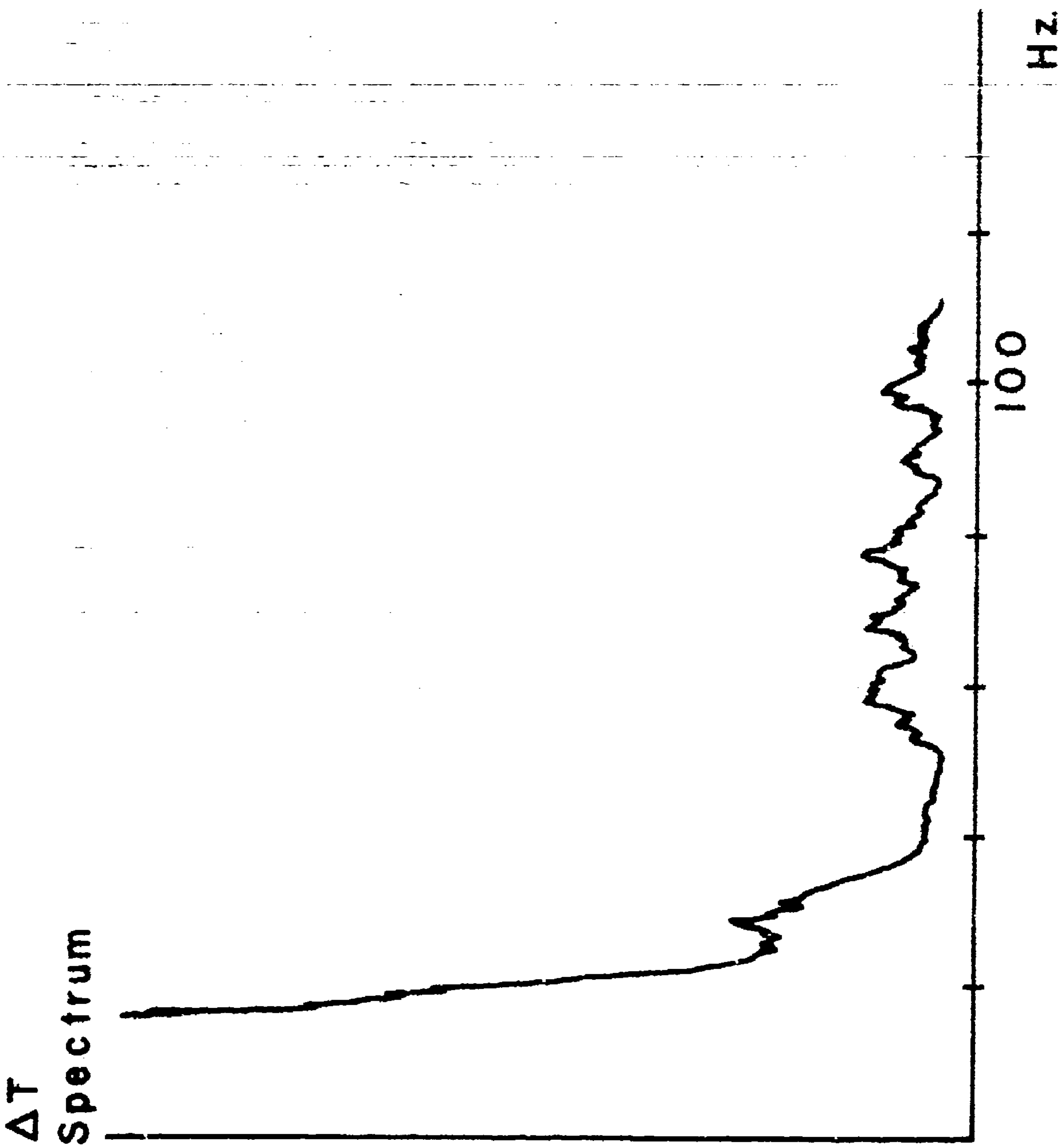


FIGURE 6

FIGURE 7

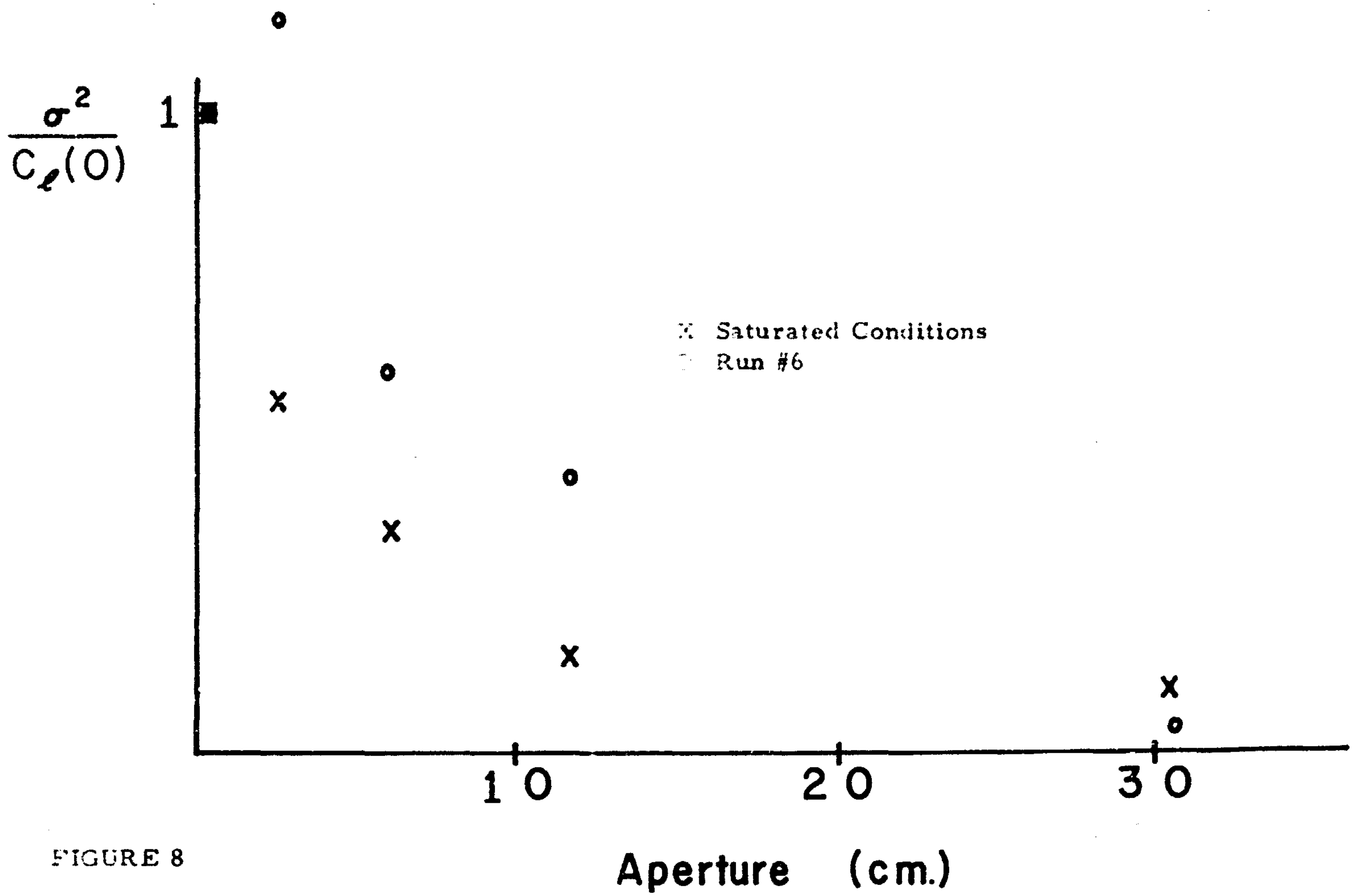

$\frac{\sigma^2}{C_\ell(0)}$
1
10
20
30
Aperture (cm.)
X Saturated Conditions
o Run #6

FIGURE 8

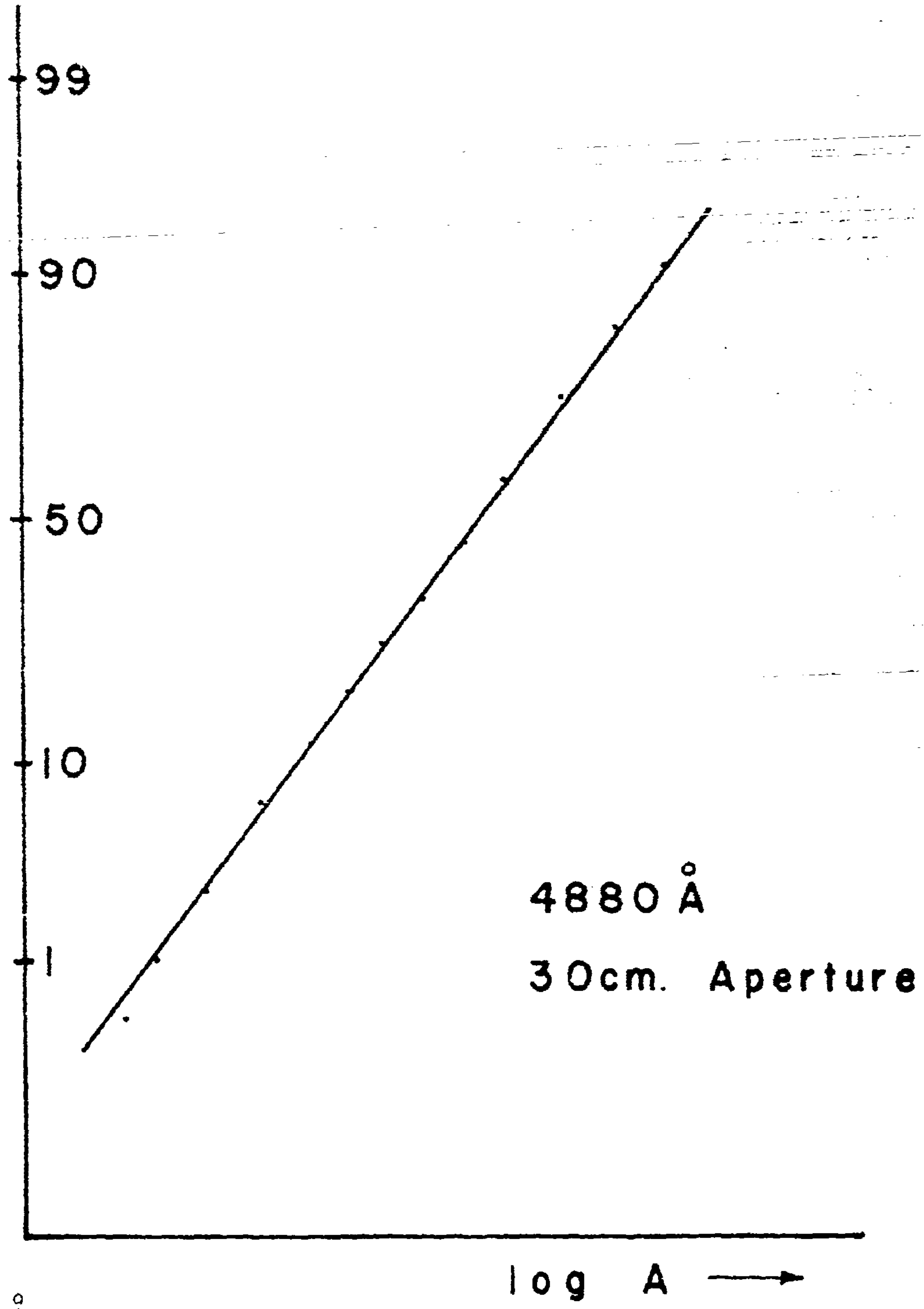


FIGURE 9

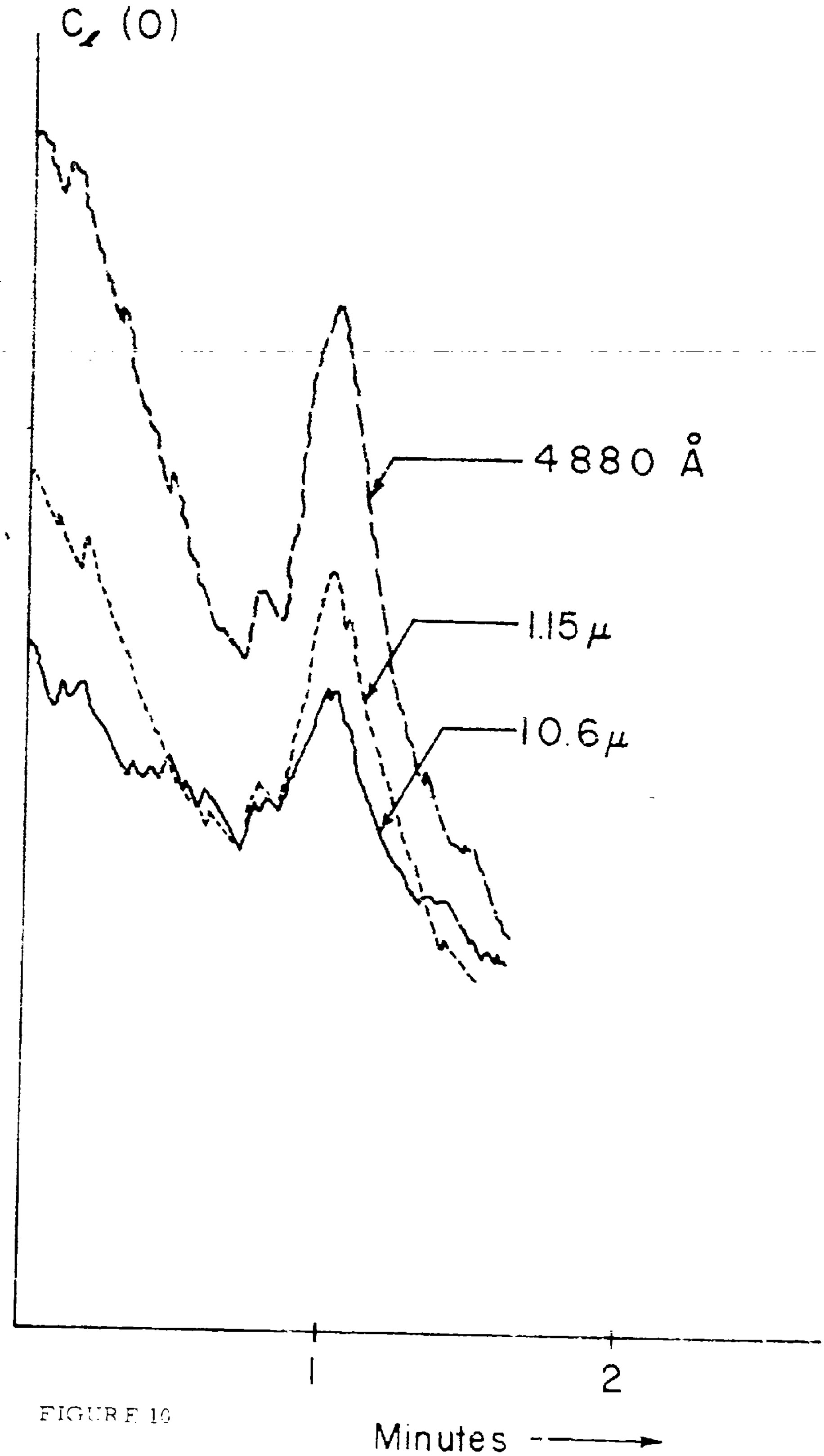
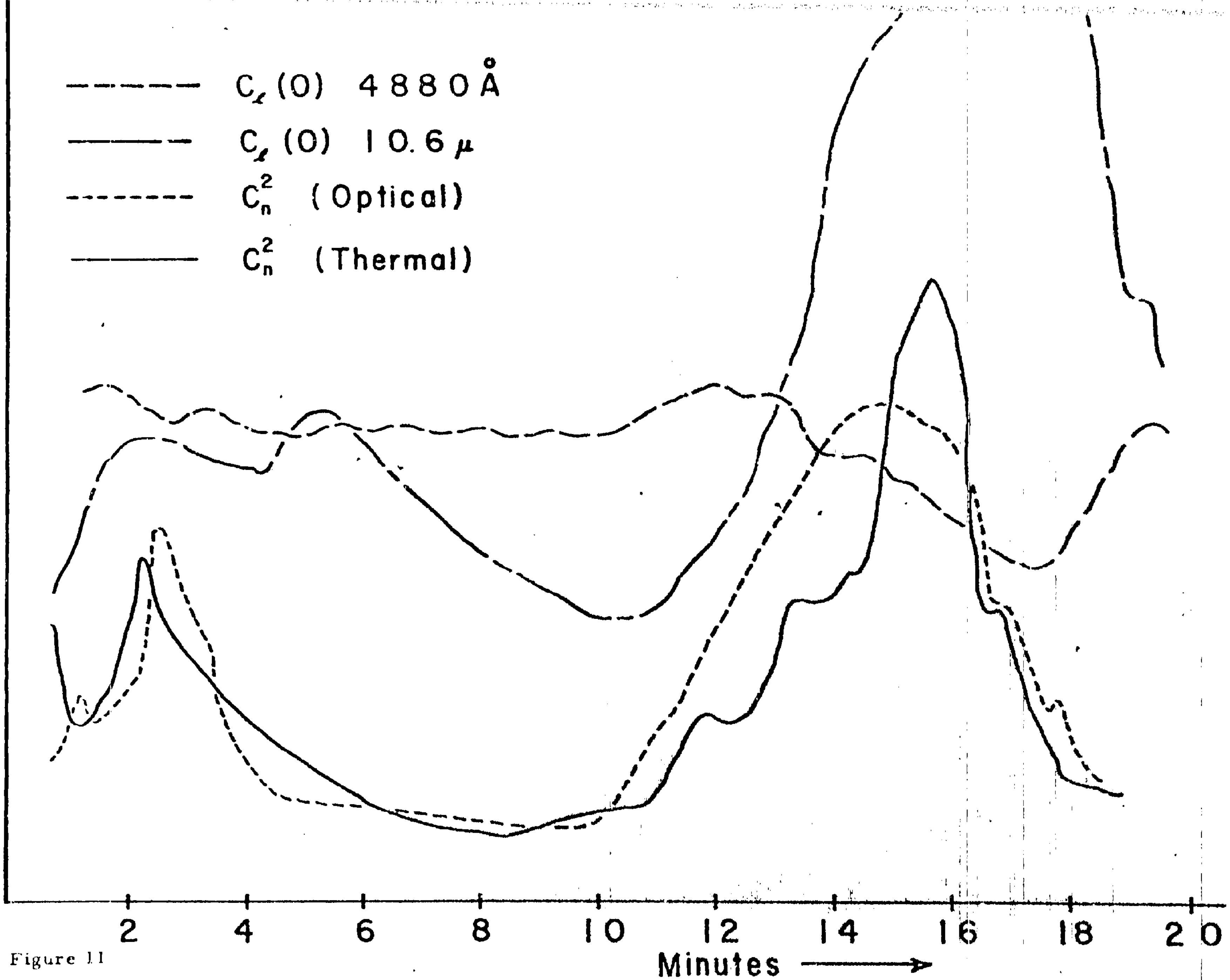


FIGURE 10



C_ℓ (0) 4880 Å
C_ℓ (0) 10.6 μ
C_n^2 (Optical)
C_n^2 (Thermal)
2
4
6
8
10
12
14
16
18
20
Minutes

Figure 11

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13. ABSTRACT

A series of significant multiwavelength laser propagation experiments ~~have been~~ conducted with point-source transmitters and independent determinations of turbulence strengths. Under non-saturated scintillation conditions, ~~we~~ find that the theoretical wavelength prediction of log amplitude variance is valid. Also, ~~we find~~ that the near- and far-infrared wavelengths do not saturate at lower variances than visible wavelengths, and large infrared variances have been measured. ~~We~~ find that different techniques for measuring the strength of turbulence yield different (but related) results. ~~We have~~ found that the multiwavelength covariance characteristics are usually independent of conditions and are near theoretical values, although certain anomalous results suggest limitations in the extent of the inertial subrange turbulence model. ~~We have~~ found that large receiver apertures do not result in the degree of reduction in total signal fluctuations that would be expected from the theory. Finally, ~~we have~~ found that simultaneous records of changing variances and turbulence strengths yield interesting characteristics which may be related to the stationarity of the medium.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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